



# **Feasibility and Conceptual Design Study for Towed Torpedo Emulator**

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## Abstract

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A study was undertaken to determine the feasibility of towing a streamlined body at various depths up to 40 m, speeds up to 20 knots, and distances of more than 250 m behind a high speed vessel. The tow-body would house a sensor package and acoustic projectors that would emulate the signature of a torpedo. In order to reduce dynamic instabilities and acoustic noise introduced by control surfaces, a tow-body 43 cm in diameter by 1.65 m long without depressor surfaces is recommended. It is also recommended that the bottom 30 m of the tow-cable have rigid fairings to minimize drag and strumming. A specialized winch and overboarding sheave are required to handle the cable fairing and sustained the required loads. The system was modeled to determine geometry and cable loads at various speeds. It was found that at a tow speed of 20 knots, a tow-body in-water weight of 227 kg, a cable tension of 16.2 kN, and a cable lay-back of 273 m, are required to achieve a depth of 40 m. One area that needs further investigation is finding a vessel with sufficient size and horsepower to deploy the tow body and tow it at the desired speed.

## Résumé

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Une étude a été entreprise afin de déterminer la faisabilité de remorquer un corps profilé à des profondeurs diverses allant jusqu'à 40 m et à des vitesses allant jusqu'à 20 nœuds sur des distances de plus de 250 m derrière un navire rapide. Le corps remorqué renfermera un ensemble de capteurs et de projecteurs acoustiques pour simuler la signature d'une torpille. Afin de réduire les instabilités dynamiques et le bruit acoustique produits par les surfaces de contrôle, un corps remorqué de 43 cm de diamètre par 1,65 m de long sans surface plongeante est recommandé. Il est également recommandé que le câble de remorquage soit équipé sur ses derniers 30 m de carénages rigides afin de minimiser la traînée et le crépinage. Un treuil spécialisé et une poulie hors-bord sont requis pour manutentionner le carénage du câble et soutenir les charges requises. Le système a été conçu de façon à déterminer la géométrie et les tensions de câble à diverses vitesses. Il a été constaté qu'à une vitesse de 20 nœuds, un corps pesant 227 kg remorqué en immersion avec une tension de câble de 16,2 nœuds déroulé sur une longueur de 273 m est requis pour obtenir une profondeur de 40 m. Un aspect qui devra être étudié plus en profondeur est la recherche d'un navire de dimension et de puissance suffisantes pour déployer ce corps et le remorquer à la vitesse voulue.

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# Executive summary

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## Introduction

A study was undertaken to determine the feasibility of constructing a towed torpedo emulator (TOTEM) device. This system would transmit both low-frequency acoustic signatures and high-frequency torpedo sonar signals, emulating a variety of torpedo types. To be realistic, the emulator must be towed at speeds approaching 20 knots and depths approaching 40 m. If successful, such a system would allow controlled, at-sea evaluations of new torpedo detection systems, without the expense and complication of using actual weapons.

## Results

The report describes a potential design for the tow-body, cable, cable-fairings, and winch system. This overall system was modeled hydrodynamically to determine cable geometry and loads at various speed-depth combinations. It was found that at a tow speed of 20 knots, a tow-body in-water weight of 227 kg, a cable tension of 16.2 kN, and a cable lay-back of 273 m, are required to achieve a depth of 40 m.

## Significance

Overall, this study shows that it is feasible to construct a torpedo emulator device, capable of operating at speeds up to 20 knots, and this work will serve as a useful guide in future developments. However, the predicted size and weight of the tow-body and the size of the winch were much larger than originally anticipated. Furthermore, the report identifies a problem in the availability of a suitable tow vessel.

## Future Plans

It is anticipated that a TOTEM system will be developed as part of the Multi-sensor Torpedo Defence Technology Demonstration Project. The next phase in such a development would be the design, construction, and testing of a prototype.

Dessureault, J.-G., and Miller, L., 2005. Feasibility and Conceptual Design Study for Towed Torpedo Emulator. DRDC Atlantic CR 2005-056, Defence R&D Canada – Atlantic.



# Sommaire

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## Introduction

Une étude a été entreprise pour déterminer la faisabilité de construire un simulateur de torpille remorqué (TOTEM). Ce système transmettrait des signatures acoustiques à basse fréquence et des signaux sonar de torpille à haute fréquence, simulant ainsi divers types de torpilles. Pour être réaliste, le simulateur doit être remorqué à des vitesses approchant les 20 nœuds et à des profondeurs de près de 40 m. En cas de réussite, un tel système permettrait d'effectuer des évaluations en mer contrôlées des nouveaux systèmes de détection de torpille, sans encourir les dépenses ni les complications accompagnant l'utilisation de véritables torpilles.

## Résultats

Le rapport décrit un système potentiel comprenant un corps remorqué, un câble, des carénages de câble et un treuil. Ce système a été conçu en tenant compte de l'hydrodynamique afin de déterminer la géométrie du câble et les charges à utiliser pour diverses combinaisons de vitesse et de profondeur. Il a été constaté qu'à une vitesse de 20 nœuds, un corps de 227 kg remorqué en immersion avec une tension de câble de 16,2 nœuds déroulé sur une longueur de 273 m est requis pour obtenir une profondeur de 40 m.

## Portée

Dans l'ensemble, l'étude démontre la faisabilité de construire un simulateur de torpille capable de fonctionner à des vitesses allant jusqu'à 20 nœuds, et elle servira de guide utile pour les développements à venir. Cependant, il appert que la dimension et le poids prévus du corps remorqué, de même que la dimension du treuil, sont beaucoup plus importants que ce à ce quoi on s'attendait. De plus, le rapport soulève le problème de disponibilité d'un navire remorqueur approprié.

## Recherches futures

On prévoit que le système TOTEM sera mis au point dans le cadre du projet de démonstration de technologie de défense contre les torpilles à partir de capteurs multiples. La prochaine étape de ce développement sera la conception, la construction et la mise à l'essai d'un prototype.

Dessureault, J.-G., and Miller, L., 2005. Feasibility and Conceptual Design Study for Towed Torpedo Emulator. DRDC Atlantic CR 2005-056, Defence R&D Canada – Atlantic.

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# 1. Introduction

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DRDC Atlantic has the intention to develop a towed system that will simulate a torpedo. The system has been named the TOWed TORpedo EMulator, TOTEM. The system is envisioned to consist of a streamlined shaped body being towed at a significant depth and lay-back distance behind a vessel. The towed body would contain acoustic projectors that could be programmed to simulate the sound signature of various torpedoes. The system would be used in armed forces training and torpedo defence R&D scenarios.

A typical torpedo can reach speeds of 60 knots with operational depth capabilities of 75 - 100 m. As well, a torpedo is designed to travel with a minimum of noise underwater making detection very difficult.

It is unrealistic to expect a towed system to duplicate these parameters. However, a towed system could be designed that would travel at considerable speed and depth. The system could be towed far enough behind a vessel such that vessel noise does not interfere with the sound emanating from the projectors in the tow body. A depth limit of 40 m and lay-back distance of 250 m are deemed to be practical parameters to enable a towed body to emulate a torpedo for training purposes.

This report investigates the feasibility of developing such a system. The towed torpedo emulator (TOTEM) system would consist of the following main components:

- Towed body that houses acoustic projectors and sensors
- Tow cable
- Overboarding sheave
- Slip-ring towing winch
- Towing vessel

Each component of the system will be evaluated with emphasis on specifying the general design parameters for the towed body and the tow cable. Then, these system components will be modelled to determine the tow loads imposed on the vessel and tow-body for various system configurations and design parameters.

## 2. The Tow Body

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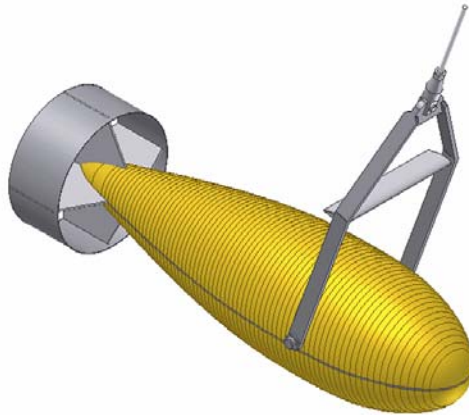
The tow body (often referred to as a fish) must house all of the necessary equipment to simulate the signature of various torpedoes. Two (2) acoustic projectors have been proposed to handle the required frequency range: a barrel stave projector approximately 16.5 cm diameter by 36 cm long, and a spherical projector approximately 10 cm in diameter. A sensor package is also required that would send pressure/depth, heading, and body orientation data to the operator station.

The overall size of the fish is determined by two requirements; sufficient enclosed volume to house the required payload and sufficient weight to pull down the tow cable to the desired depth. The required down force can be achieved either by adding ballast weight internally or by incorporating depressor control surfaces externally on the fish. Figure 1 illustrates a tow body with internal ballast. Figure 2 illustrates a tow body with external depressor wings.

Wings have the advantage of generating down force that increases with the square of the speed. The same square law applies to cable drag, resisting the cable from going down. As such, the depth of the fish does not change with speed. Wings have several disadvantages; 1) the dynamic forces on the wings are not related to the vertical axis and can cause the body to tow off to the side if the wings are not perfectly symmetrical, and 2) wings with a strong angle of attack will produce considerable flow noise. In the TOTEM system, this external flow noise would be detrimental to system performance.

A ballasted fish with no wings provides a more constant down force. This results in a more stable fish that is less affected by the heave of the ship in heavy seas. The obvious disadvantage of a ballasted fish is the increased deck weight, making handling somewhat more difficult and generally requiring a larger vessel for deployment and recovery.

A tow body without depressor control surfaces is recommended for the TOTEM system. The tow body is shown in detail in Figure 7. It is sized to accommodate the acoustic projectors in the upper portion of the body above the center-line. The ballast and instrument case would be housed in the lower portion of the body. To fit the required payload, the fish would be approximately 43 cm in diameter at its widest point and 165 cm long. A longitudinal deck plate is envisioned to fix the various payloads and provide structure for attachment of the towing bridle. The tail section of the fish would also tie into the deck plate. The tow body would weigh approx. 82 kg (180 lb) in air without ballast attached.



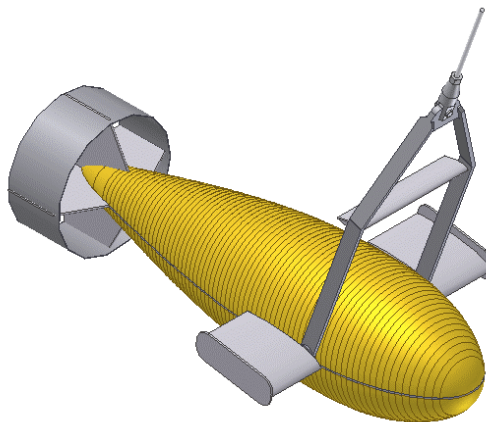
**Figure 1 Tow body without depressor wings**

A good choice of material for the external shell of the tow body is ABS. ABS has good impact resistance over a wide temperature range, can be easily vacuum formed, and is acoustically transparent.

The shape of the tow body is modelled after Moby II developed at NRE in the 1960s. Moby II was developed for high speed towing behind the military hydrofoil vessel Bras D'or. Moby II was field tested at towing speeds up to 40 knots.

The pivoting towing bridle should be located above the centre of gravity and near the centre of hydrodynamic drag for maximum static stability.

A tow body version with depressing wings is also presented (see Fig. 2). This design is not recommended due to the expected high flow noise and possible instability at high towing speeds. A tow body with depressing wings would be easier to handle on deck due to its decreased requirement for ballast weight.



**Figure 2 Tow body with depressor wings**

## 2.1 Depth Control

The depth of the tow body can be changed using three (3) different methods:

The simplest method is varying the amount of cable out. This method has the negative effect of changing the trail of the tow body (distance behind the vessel).

Removing or adding ballast to the tow body. This method involves removing the tow body shell on deck before and/or during a deployment exercise.

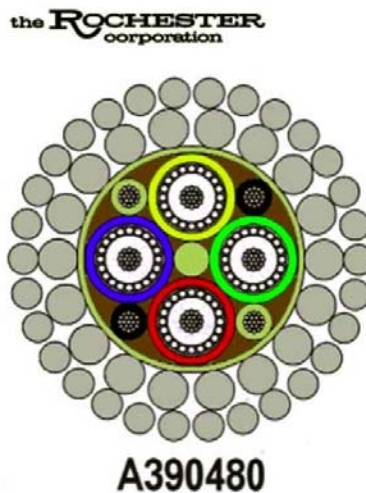
Adding a small rudder to the tail of the tow body. Adjustment of the rudder would cause the TOTEM to tow off to one side at less depth.

The method of adding and removing ballast is deemed to be the simplest depth control system, provided that dynamically changing depth while under tow is not a system requirement.

### 3. Tow Cable

The tow cable must be of sufficient length to trail the TOTEM at least 250 meters behind the vessel at a depth of 40 meters. Eight (8) 20-gauge electrical conductors are required and the mechanical strength is supplied using external, helically-wound metal armour. A typical cable that may meet the requirements for the TOTEM system is shown in Figure 3. This cable, with a diameter of 0.48” and a water weight of 0.47 kg/meter, was used in the tow load modelling exercise. The worst cable loading case (Case #3 in Table 1) has a cable tension at the winch of 16.2 kN. The breaking strength of the cable shown in figure 3 is 84.5 kN. This provides about a 5:1 safety factor on the breaking strength of the cable.

The cable diameter has a significant effect on the resulting tow loads at high speed. Every effort should be made to keep cable diameter to a minimum for the TOTEM system.



Part	Diameter		Breaking Strength		Weight in Water		Cdrs.	Zo	Coaxes	Stock
Number	mm	in	kN	lbf	kg/km	lbs/kft		Ohm		Item
A390480	12.17	0.479	84.5	19,000	469	315	4	35	4	Yes

Figure 3 Tow cable cross-section and data

#### 3.1 Cable Catenary Calculation

The cable catenary and resultant tow loads at all points along the cable were calculated with a program developed at the Bedford Institute of Oceanography (unpublished). The model is based on earlier work at the University of Bath. (see Wingham and Keshaw 1977).



The model was run with the following input variables:

water weight of body (lbs):	variable
frontal area of body (sq. ft):	1.76 (Ø18" tow body)
body drag coefficient:	0.3
water weight of cable (lb/ft):	0.31
cable diameter (in):	0.48
cable drag coefficient:	1.2
cable tangential drag coefficient:	0.02
control surface area (sq. ft):	variable
control surface lift coefficient:	0.8
control surface drag coefficient:	0.2
towing speed (knots):	variable

Using the input variables, the model calculates the cable angle from horizontal and cable tension at chosen incremental points along the cable. The chart below tabulates the depth, lay-back, scope, cable tension at surface, and cable angle at surface for various tow body input parameters. The entire modelling results for the five (5) cases tabulated below are presented in the appendix.

Modelling a cable that has a faired and unfaired section requires two (2) runs; one for the faired section and one for the unfaired section. The results are then combined together as shown in the table.

The input variables for the five (5) cases are as follows:

#### Case #1

No cable fairing, in-water tow-body weight = 227 kg (500 lbs), speed = 20 knots, no depressor control surfaces

#### Case #2

100 ft of rigid cable fairing, in-water tow-body weight = 273 kg (600 lbs), speed = 20 knots, no depressor control surfaces

#### Case #3

100 ft of rigid cable fairing, in-water tow-body weight = 227 kg (500 lbs), speed = 20 knots, no depressor control surfaces.

#### Case #4

100 ft of rigid cable fairing, in-water tow-body weight = 136 kg (300 lbs), speed = 16 knots, no depressor control surfaces

#### Case #5

100 ft of rigid cable fairing, in-water tow-body weight = 91 kg (200 lbs), speed = 20 knots, depressor control surface area = 0.50 sq. ft.

**Table 1 Cable Catenary Tabulated Results**

Case #	Speed (knot)	Body Weight in water (kg)	Section Faired or Bare	Depth (m)	Trail (m)	Scope (m)	Tension (N) at winch	Angle (deg.from hor.) at surface
1	20	227	<b>Bare</b>	<b>27.5</b>	<b>271</b>	<b>273</b>	<b>14,968</b>	<b>4.4</b>
2	20	273	Faired	16.1	25.7	30.5		
			Bare	26.5	209	211		
			<b>Combined</b>	<b>42.6</b>	<b>234.7</b>	<b>241.5</b>	<b>15,417</b>	<b>4.8</b>
3	20	227	Faired	14.8	26.5	30.5		
			Bare	27.9	240.5	242.5		
			<b>Combined</b>	<b>42.7</b>	<b>267</b>	<b>273</b>	<b>16,217</b>	<b>4.6</b>
4	16	136	Faired	14.3	26.8	30.5		
			Bare	28.4	214.5	216.7		
			<b>Combined</b>	<b>42.7</b>	<b>241.3</b>	<b>247.2</b>	<b>9,711</b>	<b>5.6</b>
5	20	91	Faired	16.1	25.7	30.5		
		(wings)	Bare	26.5	199.9	202		
			<b>Combined</b>	<b>42.6</b>	<b>225.6</b>	<b>232.5</b>	<b>15,882</b>	<b>4.8</b>

## 3.2 Modelling Results Discussion

**Case 1** clearly demonstrates the usefulness of cable fairing. At 273 m of cable pay out, the tow body has only reached a depth of 27.5 meters. To reach the target depth of 40 m, the tow body would need to be significantly heavier and a much longer cable would be required. As well, the cable flow-noise generated near the tow body may be unacceptable.

**Case 3** illustrates the effect of adding fairing to the lower portion of the cable for the same ballast weight as in case 1. The fish tows 15 m deeper at the same 20 knot speed.

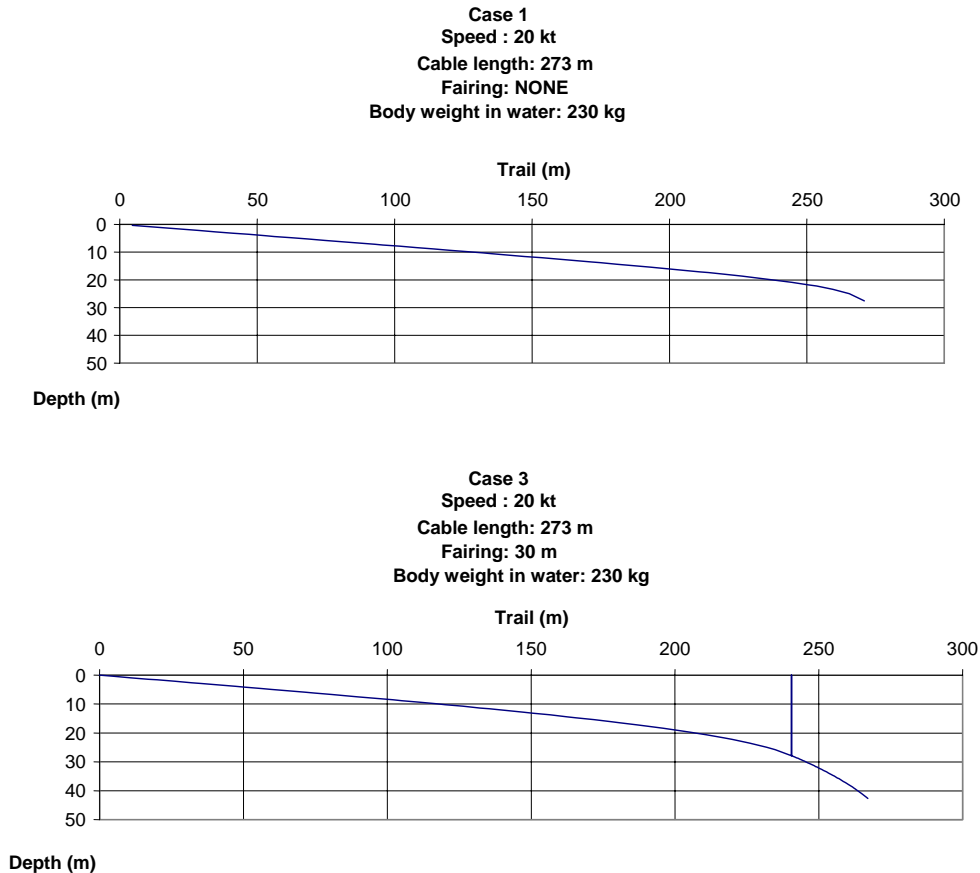
**Case 2** shows the effects of adding 46 kg (100 lbs) of extra ballast to the tow body with a faired cable. The 32 m shorter cable required to reach depth results in a decrease of cable tension at the winch of 800 N (180 lbs).

**Case 4** illustrates the dramatic reduction in ballast requirements for the tow body and the resulting decrease in cable tension at the winch with a speed reduction of 4 knots.

**Case 5** shows the significant decrease in the required ballast of the tow body when depressor wings are employed. First impressions would indicate that this would be the best design to pursue. However, use of depressor wings would introduce significant flow noise around the tow body and could easily introduce hydrodynamic instability at higher towing speeds.

The cable catenary for Case 1 and Case 3 are shown in Figure 4. In the second graph (Case 3), the vertical line at a trail distance of 240 m, indicates the start of the rigid fairing section.

**Figure 4 Plots of cable catenary for Cases 1 and 3**



### 3.3 Fairing

Cable fairing is a requirement in many towed cable systems. Fairings help to reduce cable drag through the water and eliminate detrimental cable strumming. There are basically four (4) types of cable fairings:

- Braided hair fairing consisting of nylon monofilament strands woven into a stainless braid over the armour during manufacture. Other versions feature polyester braid with polyester fringe. This type of fairing is relatively inexpensive and can be easily spooled on a winch drum. Typical drag coefficients for hairy faired cable are in the order of 1.2 – 1.4. This type is recommended for low speed towing applications or moorings.
- Strip fairing consisting of pieces of vinyl impregnated fabric woven into the cable armour during manufacture. This fairing reduces the cable drag coefficient to approximately 1.0. This type is not recommended for high speed towing applications.
- Flexible hydro-foil shaped fairing that can be attached to the cable by user. System consists of a rigid plastic swivel device with flexible hydro-foil shaped fabric attached. The foil devices are located along the cable using rings that are mechanically fastened to cable. These fairings can be spooled on a winch drum and have a drag coefficient of 0.7. These fairings are recommended for moderate speed towing applications.
- Rigid hydro-foil shaped fairing segments that are attached to the tow cable by user. The system consists of multiple segments approximately 7-10 cm long and can be installed on terminated cables. Mechanical rings attached to the cable hold the segments from slipping along the tow cable. This type of fairing is suited for higher speed towing applications with a drag coefficient in the order of 0.15 – 0.20. This type of fairing can only be wound in single layer on a winch drum due to its rigid nature.

In order to prevent strumming and reduce drag, it is necessary to install fairing on the part of the cable which is close to the fish and at an angle near normal to the flow. Strumming generates acoustic noise, increases drag, and causes mechanical fatigue of the cable.

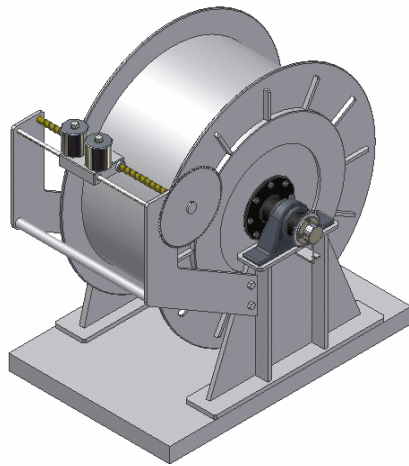
The rigid hydro-foil fairing is deemed to be the fairing most suited for the TOTEM system. Its low drag coefficient and durability minimize cable drag and strumming at tow speeds up to 20 knots. Modeling has shown that approximately 30 m of fairing is optimum for good towing performance while minimizing cable tension at the winch. A Canadian company, Odium Spectrum, manufactures rigid fairing under the trade name Tufnose™. Thirty (30) meters of fairing Model TN510 (suitable for 0.5" cable), including factory installation, would cost approx. \$6-8 thousand.

## 4. Winch

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The winch must have a large diameter drum to accommodate the minimum bend diameter of the cable and the fairing. A large drum is also required to hold the entire faired section of the cable on the outside wrap. The faired layer of cable would be wrapped in a 'tail up' configuration. Figure 5 shows the basic dimensions of a simple winch which would meet the requirements for the TOTEM system. The winch must be equipped with electrical slip-rings to maintain electrical contact while adjusting the amount of cable out. Figure 5 shows a rendered view of a suitable winch. A level wind is shown but would not be essential if the overboarding sheave was far enough from the winch to limit the fleet angle to less than 1-1/2 degrees (approx. 10 m).

The winch should have a pull rating of at least 17.0 kN at bare drum and be mounted on a deck structure able to support the reactions from this towing force.



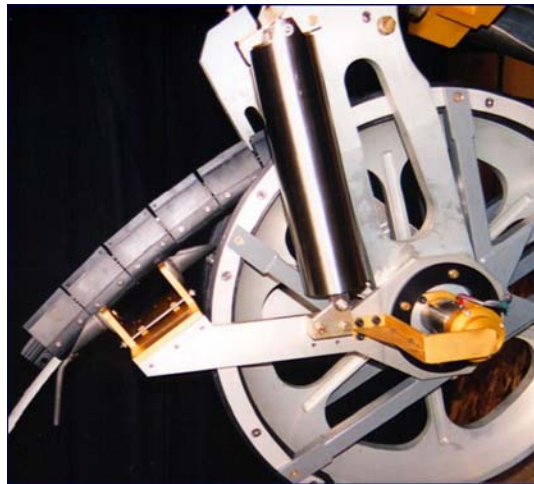
**Figure 5 Towing Winch**

## 5. Overboarding Sheave

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Rigidly faired cable requires a purpose designed over-boarding sheave. The sheave incorporates an alignment device that orients the individual fairing components prior to running over the pulley wheel. Figure 6 shows a custom-designed lightweight sheave with a fairing alignment system. The fairing shown in the figure is Tufnose™ made by Odim Spectrum. Over-boarding sheave designs that accommodate rigid fairing are readily available off-the-shelf.

A 13-mm diameter cable with Odim Spectrum TufNose™ fairings requires a sheave diameter of 40 cm (16 in.). The recommended minimum diameter for maximum life of the armoured cable is 50 cm (20 in.).



**Figure 6 Over boarding sheave with rigid fairing cable**

## 6. Towing Vessel Requirement

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The towing vessel needs to have the power to pull 15.5 - 16.5 kN at a speed of 20 knots. This represents about 180 Hp, in addition to the power required to move the vessel at that speed. At 16 knots, the additional towing horsepower requirement drops to 147. The winch will weigh approximately 1000 kg and the deck will see reactions generated by the weight of the winch and the cable tension.

As well, the vessel would need a suitable A-frame or over-boarding crane. The over-boarding support, whether an A-frame or a crane, needs to be rated for the resultant loading caused by cable tension resulting from the maximum setting of the winch brake (around 35 kN static).

A search was conducted of local vessels that could possibly meet the towing requirements for the TOTEM system. The following vessels were investigated:

- Waterworks Construction runs a 35' work boat named the MUSKRAT. The vessel is capable of 24 knots with twin 8.2 litre diesels putting out a combined horsepower of 500.
- The Coast Guard operates a 53' Erin Class Cutter named the SAMBRO. The vessel has a cruise speed of 21 knots and is equipped with 1070 total horsepower.
- The Coast Guard operates a 48' Cape Class Cutter named the ST JAMES. The vessel has a cruise speed of 22 knots and is equipped with 905 total horsepower.
- The Maritime Coastal Defence Vessels (MCDV) have a max. speed of 15 knots.
- The CCGS Frederick G. Creed is a SWATH research vessel operated by the Canadian Coast Guard based at the Institute Maurice Lamontagne in Mont-Joli QC. She has a top speed of 20 knots, but not the deck carrying capacity for this project.

None of the vessels listed are deemed to have the combination of sufficient power and/or deck space to handle the towing requirements of the Torpedo Emulator System.

## 7. Results and Conclusions

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Brooke Ocean Technology was contracted to undertake a study to determine the feasibility of using a towed body to emulate a torpedo. The target functional parameters of the TOTEM system were given as 20 knot towing speed, maximum 40 meters towing depth, and a separation between the towing vessel and the torpedo emulator tow body of 250 meters. As well, the tow body had to be sized to handle certain payload requirements and shaped to minimize flow induced noise.

Our analysis of the required tow body geometry, cable configuration, and vessel power requirements indicate that the TOTEM system, as envisioned, is feasible if the appropriate vessel can be secured to tow the system. Our initial search of local vessel inventory indicated that no such vessel can be found locally. A more detailed investigation is required.

We recommend that the MOBY II tow body geometry, developed by NRE, be adopted for the TOTEM system. The shape has been field tested and proven by NRE at very high tow speeds. Brooke Ocean has used the design successfully in a number of lower speed tow body applications.

The tow body size necessary to enclose the acoustic projector and sensor payloads was determined to be 43 cm in diameter at its widest point and 165 cm long. The overall weight in water, including ballast, would be 230-270 kgs (500-600 lbs). The construction would consist of an internal structural aluminum frame. This frame would handle the payload, towing bridle, tail, and shell attachment. Two (2) ABS shells would form the external shape of the fish.

A 12-13 mm (0.5 in) diameter armoured cable was chosen for modelling purposes. This cable size is available with the required conductors and has sufficient strength to handle the high towing loads. Modelling of the cable system indicates that 240-270 meters of cable is required to be in the water to obtain the required depth and trail. A 30 meter (100 ft) section of cable closest to the tow body should have rigid fairing attached. This reduces flow induced noise and vibration, as well as overall cable tension to a minimum.

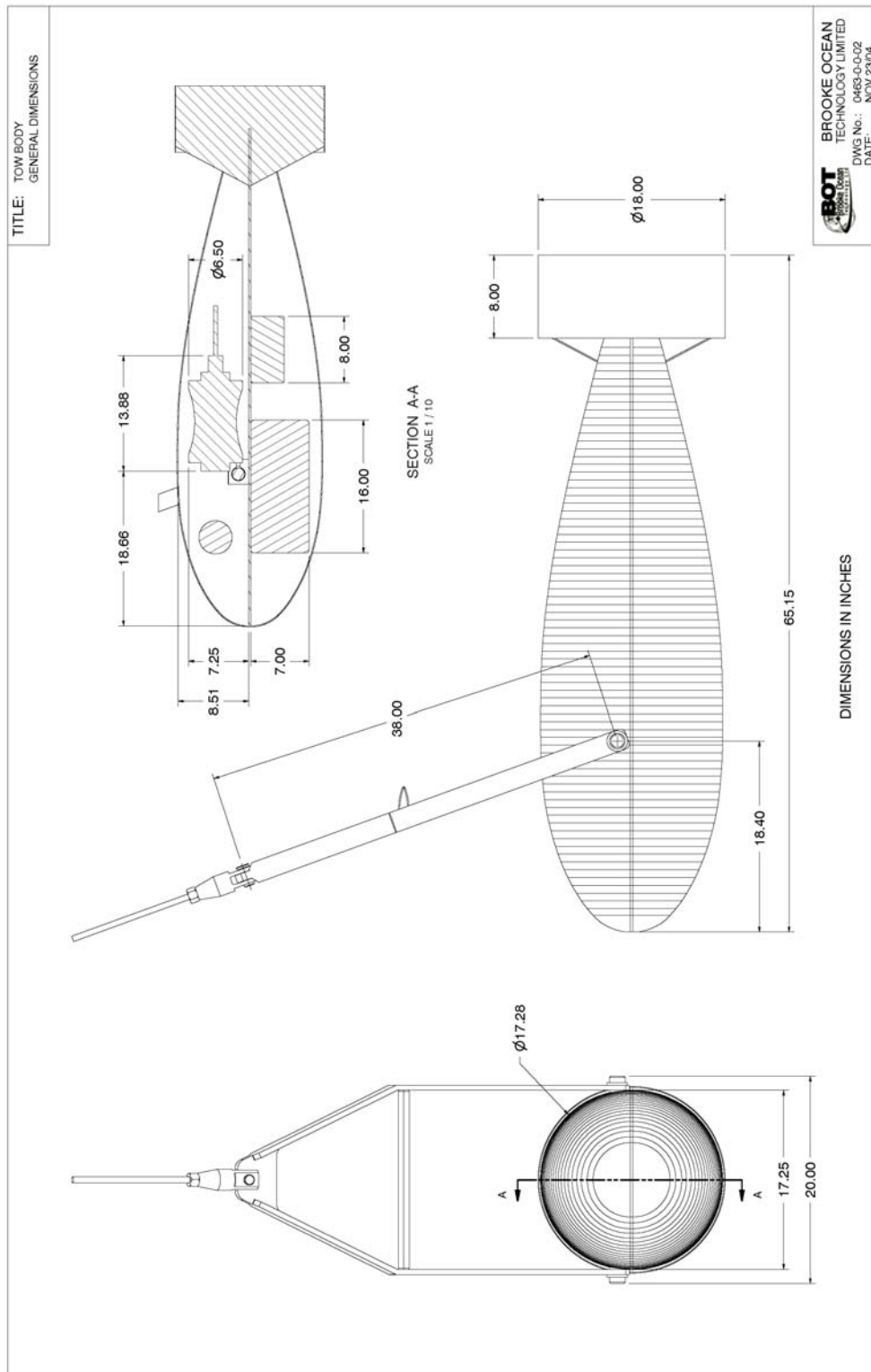
In conclusion, it is the opinion of Brooke Ocean Technology that the TOTEM system is entirely feasible. Our investigation into the required system components did not turn up any major roadblocks to a way forward. Procurement of a suitable towing vessel is the one area that may require more investigation. A reduction in towing speed for the TOTEM system may be a necessary requirement to secure a local vessel suitable for system testing.



## 8. References

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1. WINGHAM, P.V. and KESHAW, N.R. Predicting the Equilibrium Depth of a Body Towed by a Faired Cable. The University of Bath School of Engineering. Report No. 405. July 1977.



**Figure 7 Diagram of potential towed body configuration**

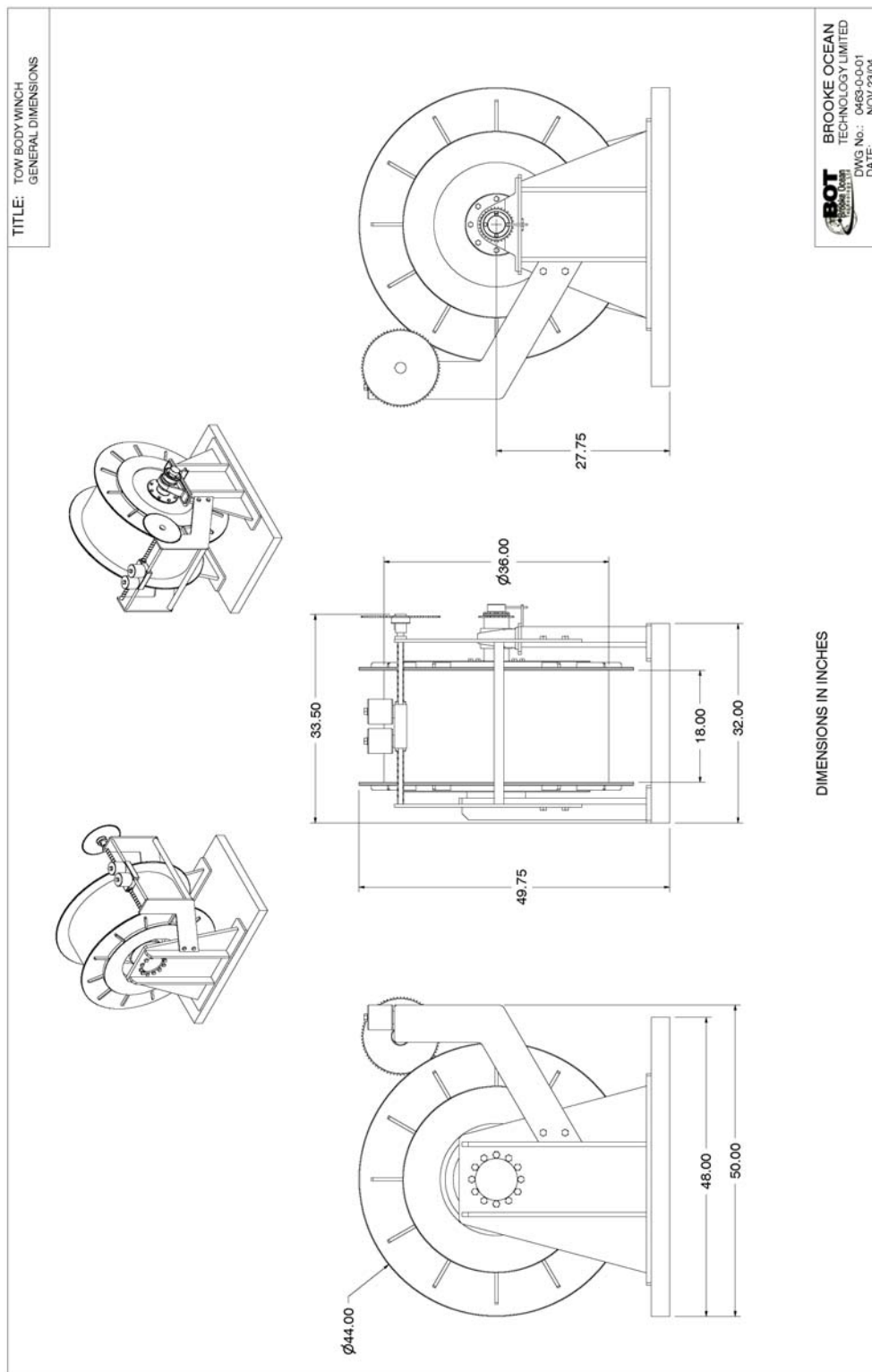


Figure 8 Diagram of possible winch

## 9. Appendix

### Filename: Case 1-bare cable

Input Variables:

Weight of Body (lb): 500

Frontal Area (sq. ft): 1.76

Body Drag Coefficient: 0.3

Weight of cable (lb/ft): 0.31

Diameter of cable (inches): 0.48

Drag Coefficient of cable: 1.2

Tangential Drag Coefficient: 0.02

Wing Area (sq. ft): 0

Wing Lift Coefficient: 0.8

Wing Drag Coefficient: 0.2

Speed (knots): 20

Initial angle (deg): 39.42387 (Calculated)

Initial tension (lb): 787.3852 (Calculated)

Trail is 888.5885 ft

Angle at the surface is 4.364824 degrees

Tension at the surface is 3365.171 lb

Scope = 895 ft

Depth of body is 90.38446 ft

There are 91 pieces of data in this data set, incremented by 10 ft

Using BARE cable at a speed of 20 knots, critical angle: 0.3212315 degrees

Incr. #	Depth (ft)	Trail (ft)	Scope (ft)	Tension (lb)	Angle (deg.)	Incr. #	Depth (ft)	Trail (ft)	Scope (ft)	Tension (lb)	Angle (deg.)
1	90.4	888.6	895.0	787.4	39.4	47	33.7	433.7	435.0	2102.8	4.6
3	81.7	870.7	875.0	832.3	17.4	49	32.1	413.8	415.0	2160.9	4.6
5	76.7	851.3	855.0	887.5	12.2	51	30.5	393.8	395.0	2218.9	4.6
7	72.9	831.7	835.0	944.4	9.8	53	28.9	373.9	375.0	2276.9	4.5
8	71.3	821.8	825.0	973.0	9.0	55	27.4	353.9	355.0	2335.0	4.5
10	68.4	802.0	805.0	1030.5	7.9	57	25.8	334.0	335.0	2393.0	4.5
12	65.8	782.2	785.0	1088.2	7.1	59	24.2	314.1	315.0	2451.0	4.5
14	63.4	762.3	765.0	1146.0	6.6	60	23.4	304.1	305.0	2480.1	4.5
16	61.1	742.5	745.0	1203.9	6.2	62	21.9	284.2	285.0	2538.1	4.5
18	59.0	722.6	725.0	1261.8	5.9	64	20.3	264.2	265.0	2596.1	4.5
20	57.0	702.7	705.0	1319.7	5.7	66	18.8	244.3	245.0	2654.2	4.4
21	56.0	692.7	695.0	1348.7	5.6	68	17.2	224.3	225.0	2712.2	4.4
23	54.1	672.8	675.0	1406.7	5.4	70	15.7	204.4	205.0	2770.2	4.4
25	52.3	652.9	655.0	1464.7	5.3	72	14.2	184.5	185.0	2828.3	4.4
27	50.5	633.0	635.0	1522.7	5.1	73	13.4	174.5	175.0	2857.3	4.4
29	48.7	613.1	615.0	1580.7	5.0	75	11.8	154.5	155.0	2915.3	4.4
31	47.0	593.1	595.0	1638.7	5.0	77	10.3	134.6	135.0	2973.4	4.4
33	45.2	573.2	575.0	1696.7	4.9	79	8.8	114.7	115.0	3031.4	4.4
34	44.4	563.3	565.0	1725.7	4.9	81	7.2	94.7	95.0	3089.5	4.4

36	42.7	543.3	545.0	1783.7	4.8	83	5.7	74.8	75.0	3147.5	4.4
38	41.0	523.4	525.0	1841.7	4.8	85	4.2	54.8	55.0	3205.6	4.4
40	39.4	503.5	505.0	1899.7	4.7	86	3.4	44.9	45.0	3234.6	4.4
42	37.8	483.5	485.0	1957.8	4.7	88	1.9	24.9	25.0	3292.6	4.4
44	36.1	463.6	465.0	2015.8	4.6	90	1.1	15.0	15.0	3321.6	4.4
46	34.5	443.7	445.0	2073.8	4.6						

**Filename: Case 2 - bare cable**

Input Variables:

Weight of Body (lb): 600

Frontal Area (sq. ft.): 1.76

Body Drag Coefficient: 0.3

Weight of cable (lb/ft): 0.31

Diameter of cable (inches): 0.48

Drag Coefficient of cable: 1.2

Tangential Drag Coefficient: 0.02

Wing Area (sq. ft): 0

Wing Lift Coefficient: 0.8

Wing Drag Coefficient: 0.2

Speed (knots): 20

Initial angle (deg): 24.3 (User Input)

Initial tension (lb): 1475 (User Input)

Trail is 685.7142 ft

Angle at the surface is 4.773195 degrees

Tension at the surface is 3466.109 lb

Depth = 87 ft

Scope of cable is 692.5639 ft

There are 71 pieces of data in this data set, incremented by 10 ft

Using FAIRED cable at a speed of 20 knots, critical angle is 0.3212315 degrees

Incr. #	Depth (ft)	Trail (ft)	Scope (ft)	Tension (lb)	Angle (deg.)	Incr. #	Depth (ft)	Trail (ft)	Scope (ft)	Tension (lb)	Angle (deg.)
1	87.0	685.7	692.6	1475.0	24.3	37	29.6	331.2	332.6	2501.7	5.7
2	83.2	676.5	682.6	1500.3	20.8	39	27.7	311.3	312.6	2559.7	5.6
4	76.9	657.5	662.6	1553.8	16.3	40	26.7	301.4	302.6	2588.7	5.5
5	74.2	647.9	652.6	1581.4	14.8	42	24.8	281.5	282.6	2646.6	5.4
7	69.5	628.4	632.6	1637.3	12.6	43	23.9	271.5	272.6	2675.6	5.4
8	67.3	618.7	622.6	1665.5	11.8	44	22.9	261.6	262.6	2704.6	5.3
10	63.5	599.0	602.6	1722.4	10.5	46	21.1	241.6	242.6	2762.6	5.3
11	61.7	589.2	592.6	1751.0	10.0	47	20.2	231.7	232.6	2791.6	5.2
13	58.4	569.5	572.6	1808.2	9.2	49	18.3	211.8	212.6	2849.6	5.2
14	56.8	559.6	562.6	1836.9	8.8	50	17.4	201.8	202.6	2878.6	5.2
15	55.3	549.7	552.6	1865.7	8.5	52	15.6	181.9	182.6	2936.6	5.1
17	52.4	529.9	532.6	1923.3	8.0	53	14.8	171.9	172.6	2965.6	5.1
18	51.1	520.0	522.6	1952.1	7.8	55	13.0	152.0	152.6	3023.6	5.0
20	48.4	500.2	502.6	2009.8	7.4	56	12.1	142.0	142.6	3052.6	5.0
21	47.2	490.3	492.6	2038.7	7.2	58	10.4	122.1	122.6	3110.6	5.0
23	44.7	470.4	472.6	2096.5	6.9	59	9.5	112.2	112.6	3139.6	4.9

24	43.5	460.5	462.6	2125.4	6.8	60	8.7	102.2	102.6	3168.6	4.9
26	41.2	440.6	442.6	2183.2	6.5	62	7.0	82.3	82.6	3226.6	4.9
27	40.1	430.7	432.6	2212.1	6.4	63	6.1	72.3	72.6	3255.6	4.9
29	37.9	410.8	412.6	2270.0	6.2	65	4.4	52.4	52.6	3313.6	4.8
30	36.8	400.9	402.6	2299.0	6.1	66	3.6	42.4	42.6	3342.6	4.8
31	35.7	390.9	392.6	2327.9	6.1	68	1.9	22.5	22.6	3400.7	4.8
33	33.7	371.0	372.6	2385.9	5.9	69	1.0	12.5	12.6	3429.7	4.8
34	32.6	361.1	362.6	2414.8	5.8	71	0.2	2.6	2.6	3458.7	4.8
36	30.6	341.2	342.6	2472.8	5.7						

**Filename: Case 2 - faired cable**

Input Variables:

Weight of Body (lb): 600

Frontal Area (sq. ft): 1.76

Body Drag Coefficient: 0.3

Weight of cable (lb/ft): 0.31

Diameter of cable (inches): 0.51

Drag Coefficient of cable: 0.25

Tangential Drag Coefficient: 0.02

Wing Area (sq. ft): 0

Wing Lift Coefficient: 0.8

Wing Drag Coefficient: 0.2

Speed (knots): 20

Initial angle (deg): 44.61179 (Calculated)

Initial tension (lb): 854.386 (Calculated)

Trail is 84.40195 ft

Angle at the surface is 24.36346 degrees

Tension at the surface is 1475.145 lb

Scope = 100 ft

Depth of body is 52.73502 ft

There are 11 pieces of data in this data set, incremented by 10 ft

Using FAIRED cable at a speed of 20 knots, critical angle: 1.03736 degrees

Incr. #	Depth (ft)	Trail (ft)	Scope (ft)	Tension (lb)	Angle (deg.)	Incr. #	Depth (ft)	Trail (ft)	Scope (ft)	Tension (lb)	Angle (deg.)
1	52.7	84.4	100.0	854.4	44.6	7	17.9	35.8	40.0	1232.9	29.2
2	46.0	77.0	90.0	917.5	40.7	8	13.1	27.0	30.0	1294.4	27.8
3	39.6	69.3	80.0	981.2	37.6	9	8.6	18.1	20.0	1355.3	26.5
4	33.7	61.2	70.0	1044.8	34.9	10	4.2	9.1	10.0	1415.5	25.4
5	28.2	52.9	60.0	1108.1	32.7	11	4.2	9.1	10.0	1415.5	25.4
6	22.9	44.4	50.0	1170.8	30.8						

**Filename: Case 3 - bare cable**

Input Variables:

Weight of Body (lb): 500

Frontal Area (sq. ft): 1.76

Body Drag Coefficient: 0.3

Weight of cable (lb/ft): 0.31

Diameter of cable (inches): 0.48  
 Drag Coefficient of cable: 1.2  
 Tangential Drag Coefficient: 0.02  
 Wing Area (sq. ft): 0  
 Wing Lift Coefficient: 0.8  
 Wing Drag Coefficient: 0.2  
 Speed (knots): 20  
 Initial angle (deg): 22.9 (Calculated)  
 Initial tension (lb): 1353 (Calculated)  
 Trail is 789.0922 ft  
 Angle at the surface is 4.598664 degrees  
 Tension at the surface is 3645.948 lb  
 Depth = 91.4 ft  
 Scope of cable is 795.5798 ft  
 There are 81 pieces of data in this data set, incremented by 10 ft  
 Using BARE cable at a speed of 20 knots, critical angle: 0.3212315 degrees

Incr. #	Depth (ft)	Trail (ft)	Scope (ft)	Tension (lb)	Angle (deg.)	Incr. #	Depth (ft)	Trail (ft)	Scope (ft)	Tension (lb)	Angle (deg.)
1	91.4	789.1	795.6	1353	22.9	42	32.5	384.2	385.6	2527.5	5.3
3	84.7	770.3	775.6	1405.5	17	44	30.7	364.3	365.6	2585.5	5.2
4	81.9	760.7	765.6	1432.9	15.2	46	28.9	344.4	345.6	2643.4	5.1
6	77.1	741.3	745.6	1488.7	12.7	47	28	334.4	335.6	2672.4	5.1
8	73	721.7	725.6	1545.3	11	49	26.3	314.5	315.6	2730.4	5
9	71.1	711.9	715.6	1573.8	10.4	51	24.5	294.6	295.6	2788.5	5
11	67.7	692.1	695.6	1631	9.4	52	23.7	284.6	285.6	2817.5	5
13	64.6	672.4	675.6	1688.5	8.6	54	21.9	264.7	265.6	2875.5	4.9
14	63.1	662.5	665.6	1717.2	8.3	56	20.2	244.7	245.6	2933.5	4.9
16	60.3	642.7	645.6	1774.8	7.8	57	19.4	234.8	235.6	2962.5	4.9
18	57.7	622.9	625.6	1832.5	7.3	59	17.7	214.9	215.6	3020.5	4.8
19	56.4	612.9	615.6	1861.4	7.1	61	16	194.9	195.6	3078.5	4.8
21	54	593.1	595.6	1919.2	6.8	62	15.2	185	185.6	3107.5	4.8
22	52.8	583.2	585.6	1948.1	6.7	64	13.5	165	165.6	3165.5	4.8
24	50.5	563.3	565.6	2006	6.4	65	12.7	155.1	155.6	3194.6	4.8
26	48.3	543.4	545.6	2063.9	6.2	67	11	135.1	135.6	3252.6	4.7
27	47.2	533.5	535.6	2092.8	6.1	69	9.4	115.2	115.6	3310.6	4.7
29	45.1	513.6	515.6	2150.7	6	70	8.5	105.2	105.6	3339.6	4.7
31	43.1	493.7	495.6	2208.7	5.8	72	6.9	85.3	85.6	3397.6	4.7
32	42.1	483.7	485.6	2237.6	5.7	74	5.3	65.4	65.6	3455.7	4.7
34	40.1	463.8	465.6	2295.6	5.6	75	4.5	55.4	55.6	3484.7	4.6
36	38.2	443.9	445.6	2353.5	5.5	77	2.9	35.5	35.6	3542.7	4.6
37	37.2	434	435.6	2382.5	5.5	79	1.3	15.5	15.6	3600.7	4.6
39	35.3	414.1	415.6	2440.5	5.4	80	1.3	15.5	15.6	3600.7	4.6
41	33.5	394.2	395.6	2498.5	5.3						

**Filename: Case 3 - faired cable**

Input Variables:

Weight of Body (lb): 500

Frontal Area (sq ft): 1.76  
 Body Drag Coefficient: 0.3  
 Weight of cable (lb/ft): 0.31  
 Diameter of cable (inches): 0.48  
 Drag Coefficient of cable: 0.25  
 Tangential Drag Coefficient: 0.02  
 Wing Area (sq ft): 0  
 Wing Lift Coefficient: 0.8  
 Wing Drag Coefficient: 0.2  
 Speed (knots): 20  
 Initial angle (deg): 39.42387 (Calculated)  
 Initial tension (lb): 787.3852 (Calculated)  
 Trail is 87.02641 ft  
 Angle at the surface is 22.76349 degrees  
 Tension at the surface is 1363.685 lb  
 Scope = 100 ft  
 Depth of body is 48.58735 ft  
 There are 51 pieces of data in this data set, incremented by 2 ft  
 Using FAIRED cable at a speed of 20 knots, critical angle: 1.180559 degrees

Incr. #	Depth (ft)	Trail (ft)	Scope (ft)	Tension (lb)	Angle (deg.)	Incr. #	Depth (ft)	Trail (ft)	Scope (ft)	Tension (lb)	Angle (deg.)
1	48.6	87	100	787.4	39.4	27	20.4	43.4	48	1094.4	28
2	47.3	85.5	98	799.4	38.8	28	19.5	41.7	46	1105.9	27.7
3	46.1	83.9	96	811.4	38.1	29	18.5	39.9	44	1117.4	27.4
4	44.9	82.3	94	823.4	37.5	30	17.6	38.1	42	1128.8	27.2
5	43.6	80.7	92	835.4	36.9	31	16.7	36.3	40	1140.2	26.9
6	42.5	79.1	90	847.4	36.4	32	15.8	34.6	38	1151.6	26.7
7	41.3	77.5	88	859.4	35.8	33	14.9	32.8	36	1163	26.4
8	40.1	75.9	86	871.3	35.3	34	14	31	34	1174.3	26.2
9	39	74.3	84	883.3	34.8	35	13.1	29.2	32	1185.7	25.9
10	37.8	72.6	82	895.2	34.3	36	12.3	27.4	30	1197	25.7
11	36.7	70.9	80	907.1	33.8	37	11.4	25.6	28	1208.2	25.5
12	35.6	69.3	78	919	33.4	38	10.6	23.8	26	1219.5	25.2
13	34.5	67.6	76	930.9	32.9	40	8.9	20.1	22	1241.9	24.8
15	32.4	64.2	72	954.5	32.1	41	8	18.3	20	1253.1	24.6
16	31.3	62.5	70	966.3	31.7	42	7.2	16.5	18	1264.3	24.4
17	30.3	60.8	68	978.1	31.3	43	6.4	14.7	16	1275.4	24.2
18	29.2	59.1	66	989.8	30.9	44	5.6	12.9	14	1286.5	24
19	28.2	57.4	64	1001.5	30.6	45	4.7	11	12	1297.6	23.8
20	27.2	55.7	62	1013.2	30.2	46	3.9	9.2	10	1308.7	23.6
21	26.2	53.9	60	1024.9	29.9	47	3.1	7.4	8	1319.7	23.5
22	25.2	52.2	58	1036.6	29.5	48	2.3	5.5	6	1330.7	23.3
23	24.2	50.5	56	1048.2	29.2	49	1.6	3.7	4	1341.7	23.1
24	23.2	48.7	54	1059.8	28.9	50	0.8	1.8	2	1352.7	22.9
25	22.3	47	52	1071.3	28.6	51	0.8	1.8	2	1352.7	22.9
26	21.3	45.2	50	1082.9	28.3						



**Filename: Case 4 - bare cable**

Input Variables:

Weight of Body (lb): 300

Frontal Area (sq ft): 1.76

Body Drag Coefficient: 0.3

Weight of cable (lb/ft): 0.31

Diameter of cable (inches): 0.48

Drag Coefficient of cable: 1.2

Tangential Drag Coefficient: 0.02

Wing Area (sq. ft): 0

Wing Lift Coefficient: 0.8

Wing Drag Coefficient: 0.2

Speed (knots): 16

Initial angle (deg): 22.18 (Calculated)

Initial tension (lb): 863.6 (Calculated)

Trail is 703.8058 ft

Angle at the surface is 5.587366 degrees

Tension at the surface is 2183.274 lb

Depth = 93.1 ft

Scope of cable is 710.9323 ft

There are 144 pieces of data in this data set, incremented by 5 ft

Using BARE cable at a speed of 16 knots, critical angle: 0.5019166 degrees

Incr. #	Depth (ft)	Trail (ft)	Scope (ft)	Tension (lb)	Angle (deg.)	Incr. #	Depth (ft)	Trail (ft)	Scope (ft)	Tension (lb)	Angle (deg.)
1	93.1	703.8	710.9	863.6	22.2	74	35.0	344.2	345.9	1538.0	6.2
4	88.0	689.7	695.9	889.6	18.1	77	33.4	329.2	330.9	1566.0	6.1
7	83.7	675.3	680.9	916.3	15.4	80	31.8	314.3	315.9	1593.9	6.1
10	79.9	660.8	665.9	943.5	13.6	83	30.2	299.4	300.9	1621.9	6.0
13	76.6	646.2	650.9	970.9	12.2	86	28.6	284.5	285.9	1649.9	6.0
16	73.5	631.5	635.9	998.5	11.2	89	27.1	269.6	270.9	1677.9	6.0
19	70.7	616.8	620.9	1026.2	10.4	92	25.5	254.7	255.9	1705.8	5.9
22	68.1	602.0	605.9	1053.9	9.7	95	24.0	239.7	240.9	1733.8	5.9
25	65.7	587.2	590.9	1081.7	9.2	98	22.4	224.8	225.9	1761.8	5.9
27	64.1	577.3	580.9	1100.3	8.9	101	20.9	209.9	210.9	1789.8	5.8
30	61.9	562.5	565.9	1128.1	8.5	104	19.4	195.0	195.9	1817.8	5.8
33	59.7	547.7	550.9	1156.0	8.1	107	17.9	180.0	180.9	1845.7	5.8
36	57.6	532.8	535.9	1183.9	7.8	110	16.4	165.1	165.9	1873.7	5.8
39	55.6	517.9	520.9	1211.8	7.6	113	14.9	150.2	150.9	1901.7	5.7
42	53.6	503.1	505.9	1239.8	7.4	116	13.4	135.3	135.9	1929.7	5.7
45	51.7	488.2	490.9	1267.7	7.2	119	11.9	120.3	120.9	1957.7	5.7
48	49.9	473.3	475.9	1295.6	7.0	121	10.9	110.4	110.9	1976.3	5.7
51	48.1	458.4	460.9	1323.6	6.9	124	9.4	95.5	95.9	2004.3	5.7
54	46.3	443.5	445.9	1351.5	6.8	127	7.9	80.5	80.9	2032.3	5.7
57	44.5	428.6	430.9	1379.5	6.7	130	6.4	65.6	65.9	2060.3	5.6
60	42.8	413.7	415.9	1407.5	6.6	133	5.0	50.7	50.9	2088.3	5.6
63	41.1	398.8	400.9	1435.4	6.5	136	3.5	35.8	35.9	2116.2	5.6
66	39.4	383.9	385.9	1463.4	6.4	139	2.0	20.8	20.9	2144.2	5.6

69	37.7	369.0	370.9	1491.4	6.3	142	0.6	5.9	5.9	2172.2	5.6
72	36.1	354.1	355.9	1519.3	6.2	145	0.0	0.0	0.0	2183.3	5.6

**Filename: Case 4 - faired cable**

Input Variables:

Weight of Body (lb): 300

Frontal Area (sq ft): 1.76

Body Drag Coefficient: 0.3

Weight of cable (lb/ft): 0.31

Diameter of cable (inches): 0.48

Drag Coefficient of cable: 0.25

Tangential Drag Coefficient: 0.02

Wing Area (sq. ft): 0

Wing Lift Coefficient: 0.8

Wing Drag Coefficient: 0.2

Speed (knots): 16

Initial angle (deg): 37.62226 (Calculated)

Initial tension (lb): 491.4691 (Calculated)

Trail is 88.00352 ft

Angle at the surface is 22.17845 degrees

Tension at the surface is 863.5538 lb

Scope = 100 ft

Depth of body is 46.89711 ft

There are 21 pieces of data in this data set, incremented by 5 ft

Using FAIRED cable at a speed of 16 knots, critical angle: 1.890925 degrees

Incr. #	Depth (ft)	Trail (ft)	Scope (ft)	Tension (lb)	Angle (deg.)	Incr. #	Depth (ft)	Trail (ft)	Scope (ft)	Tension (lb)	Angle (deg.)
1	46.9	88.0	100.0	491.5	37.6	12	18.4	41.0	45.0	701.2	26.5
2	43.9	84.0	95.0	511.0	36.1	13	16.2	36.6	40.0	719.6	25.9
3	41.0	79.9	90.0	530.5	34.7	14	14.0	32.1	35.0	737.9	25.4
4	38.2	75.8	85.0	549.9	33.5	15	11.9	27.5	30.0	756.2	24.8
5	35.5	71.6	80.0	569.2	32.3	16	9.8	23.0	25.0	774.3	24.3
6	32.8	67.3	75.0	588.4	31.3	17	7.8	18.4	20.0	792.3	23.8
7	30.3	63.0	70.0	607.4	30.3	18	5.8	13.8	15.0	810.3	23.4
8	27.8	58.7	65.0	626.4	29.5	19	3.8	9.2	10.0	828.1	23.0
9	25.4	54.3	60.0	645.3	28.7	20	1.9	4.6	5.0	845.9	22.6
10	23.0	49.9	55.0	664.0	27.9	21	1.9	4.6	5.0	845.9	22.6
11	20.7	45.5	50.0	682.7	27.2						

**Filename: Case 5 - bare cable**

Input Variables:

Weight of Body (lb): 200

Frontal Area (sq ft): 1.76

Body Drag Coefficient: 0.3

Weight of cable (lb/ft): 0.3

Diameter of cable (inches): 0.5

Drag Coefficient of cable: 1.2

Tangential Drag Coefficient: 0.02  
 Wing Area (sq. ft): 0.5  
 Wing Lift Coefficient: 0.8  
 Wing Drag Coefficient: 0.2  
 Speed (knots): 20  
 Initial angle (deg): 25 (Calculated)  
 Initial tension (lb): 1589 (Calculated)  
 Trail is 655.8052 ft  
 Angle at the surface is 4.776482 degrees  
 Tension at the surface is 3570.674 lb  
 Depth = 87 ft  
 Scope of cable is 663.0597 ft  
 There are 134 pieces of data in this data set, incremented by 5 ft  
 Using BARE cable at a speed of 20 knots, critical angle: .2984348 degrees

Incr. #	Depth (ft)	Trail (ft)	Scope (ft)	Tension (lb)	Angle (deg.)	Incr. #	Depth (ft)	Trail (ft)	Scope (ft)	Tension (lb)	Angle (deg.)
1	87.0	655.8	663.1	1589.0	25.0	69	29.3	321.7	323.1	2595.6	5.9
4	81.3	642.0	648.1	1628.9	20.3	72	27.8	306.8	308.1	2640.8	5.8
6	78.0	632.5	638.1	1656.7	18.1	75	26.3	291.9	293.1	2686.1	5.7
9	73.6	618.1	623.1	1699.3	15.6	78	24.8	277.0	278.1	2731.3	5.6
12	69.8	603.6	608.1	1742.6	13.9	80	23.8	267.0	268.1	2761.5	5.6
15	66.4	589.0	593.1	1786.5	12.5	83	22.4	252.1	253.1	2806.7	5.5
17	64.3	579.3	583.1	1815.9	11.7	86	20.9	237.1	238.1	2852.0	5.4
20	61.4	564.5	568.1	1860.3	10.8	89	19.5	222.2	223.1	2897.2	5.4
23	58.7	549.8	553.1	1904.8	10.1	91	18.6	212.2	213.1	2927.4	5.3
26	56.1	535.0	538.1	1949.5	9.4	94	17.2	197.3	198.1	2972.7	5.3
28	54.5	525.1	528.1	1979.4	9.1	97	15.8	182.4	183.1	3018.0	5.2
31	52.2	510.3	513.1	2024.2	8.6	99	14.9	172.4	173.1	3048.2	5.2
34	50.0	495.5	498.1	2069.1	8.2	102	13.6	157.5	158.1	3093.4	5.1
37	47.9	480.6	483.1	2114.1	7.9	105	12.3	142.5	143.1	3138.7	5.1
39	46.6	470.7	473.1	2144.1	7.7	108	10.9	127.6	128.1	3184.0	5.0
42	44.6	455.8	458.1	2189.2	7.4	110	10.1	117.6	118.1	3214.2	5.0
45	42.7	441.0	443.1	2234.2	7.1	113	8.8	102.7	103.1	3259.5	5.0
47	41.5	431.0	433.1	2264.3	7.0	116	7.5	87.7	88.1	3304.8	4.9
50	39.7	416.2	418.1	2309.4	6.8	119	6.2	72.8	73.1	3350.1	4.9
53	37.9	401.3	403.1	2354.6	6.6	121	5.3	62.8	63.1	3380.2	4.9
56	36.2	386.4	388.1	2399.7	6.4	124	4.0	47.9	48.1	3425.5	4.9
58	35.1	376.4	378.1	2429.9	6.3	127	2.8	32.9	33.1	3470.8	4.8
61	33.5	361.5	363.1	2475.0	6.2	130	1.5	18.0	18.1	3516.1	4.8
64	31.9	346.6	348.1	2520.2	6.1	132	0.7	8.0	8.1	3546.3	4.8
67	30.3	331.7	333.1	2565.5	6.0	135	0.0	0.0	0.0	3570.7	4.8

**Filename: Case 5 - faired cable**

Input Variables:

Weight of Body (lb): 200  
 Frontal Area (sq. ft): 1.76  
 Body Drag Coefficient: 0.3

Weight of cable (lb/ft): 0.3  
 Diameter of cable (inches): 0.5  
 Drag Coefficient of cable): 0.25  
 Tangential Drag Coefficient: 0.02  
 Wing Area (sq. ft): 0.5  
 Wing Lift Coefficient: 0.8  
 Wing Drag Coefficient: 0.2  
 Speed (knots): 20  
 Initial angle (deg): 42.4115 (Calculated)  
 Initial tension (lb): 979.819 (Calculated)  
 Trail is 84.40369 ft  
 Angle at the surface is 25.39626 degrees  
 Tension at the surface is 1589.406 lb  
 Scope = 100 ft  
 Depth of body is 52.97921 ft  
 There are 21 pieces of data in this data set, incremented by 5 ft  
 Using FAIRED cable at a speed of 20 knots, critical angle: 1.053647 degrees

Incr. #	Depth (ft)	Trail (ft)	Scope (ft)	Tension (lb)	Angle (deg.)	Incr. #	Depth (ft)	Trail (ft)	Scope (ft)	Tension (lb)	Angle (deg.)
1	53.0	84.4	100.0	979.8	42.4	12	21.0	39.8	45.0	1320.6	30.5
2	49.7	80.7	95.0	1010.9	40.9	13	18.4	35.5	40.0	1351.0	29.8
3	46.4	76.8	90.0	1042.1	39.5	14	16.0	31.1	35.0	1381.2	29.2
4	43.3	72.9	85.0	1073.4	38.1	15	13.6	26.8	30.0	1411.4	28.5
5	40.3	69.0	80.0	1104.6	36.9	16	11.2	22.3	25.0	1441.4	27.9
6	37.3	65.0	75.0	1135.7	35.8	17	8.9	17.9	20.0	1471.2	27.4
7	34.4	60.9	70.0	1166.8	34.8	18	6.6	13.5	15.0	1501.0	26.8
8	31.6	56.7	65.0	1197.8	33.8	19	4.4	9.0	10.0	1530.6	26.3
9	28.8	52.6	60.0	1228.6	32.9	20	2.2	4.5	5.0	1560.1	25.9
10	26.1	48.4	55.0	1259.4	32.1	21	2.2	4.5	5.0	1560.1	25.9
11	23.5	44.1	50.0	1290.1	31.3						

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(U) A study was undertaken to determine the feasibility of towing a streamlined body at various depths up to 40m, speeds up to 20knots, and distances of more than 250m behind a high speed vessel. The tow-body would house a sensor package and acoustic projectors that would emulate the signature of a torpedo. In order to reduce dynamic instabilities and acoustic noise introduced by control surfaces, a tow-body 43cm in diameter by 1.65m long without depressor surfaces is recommended. It is also recommended that the bottom 30m of the tow-cable have rigid fairings to minimize drag and strumming. A specialized winch and over-boarding sheave are required to handle the cable fairing and sustained the required loads. The system was modeled to determine geometry and cable loads at various speeds. It was found that at a tow speed of 20knots, a tow-body in-water weight of 227kg, a cable tension of 16.2kN, and a cable lay-back of 273m, are required to achieve a depth of 40m. One area that needs further investigation is finding a vessel with sufficient size and horsepower to deploy the tow body and tow it at the desired speed.

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Torpedo, tow-body, cable fairings

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